Phosphorus Uptake by Rapeseed from Different Depths in the Soil

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1. Introduction

In Saskatchewan under a semi-arid climate, the surface layer (0-15 cm) of the soil often is too dry to support extensive plant growth. Most native plants found in this region are deep rooted and obtain significant quantities of nutrients and moisture from depths below the top 15 cm soil layer. Similarly, many of the successful commercial crops such as rapeseed and wheat grown in the prairie provinces have root systems that explore the soil depths. These facts have been clarified by many studies that have, for instance, shown a significant correlation between the uptake of a mobile element such as nitrate nitrogen by plants to the amount of NO_3-N in the top 60 cm of the soil.

Phosphorus, a relatively non-mobile element, has not shown this same relationship as available phosphorus (measured as $NaHCO_3$-extractable P) in the top 15 cm soil depth showed a better correlation with plant phosphorus uptake than does the same assessment to a depth of 60 cm. Many reasons have been advanced to explain this, and most of these concentrate on the relative immobility of the $H_2PO_4^-$ ion in the soil and on the percentage of roots in the various soil horizons. However some soils, especially light textured soils, have appreciable amounts of $NaHCO_3$-extractable P below the top 15 cm. As the top 15 cm of the soil usually contain very small amounts of available water during the growing season in light textured soils, some of the subsoil P must contribute to the nutrition of the plants. The extent of the contribution of subsoil phosphorus to plant nutrition and yields is unknown.

In the last few years, interrelated investigations in this area have been carried out in Saskatoon. In 1971, Mr. J. H. Farley and Dr. E. H. Halstead of the Department of Soil Science, started a series of growth chamber experiments to monitor root elongation of wheat and rapeseed plant roots *in situ*, and to compare nutrient uptake at different depths in the profile. Concurrently, Mr. H. Ukrainetz, C.D.A. Research Institute, started greenhouse and field experiments to measure the contribution of subsoil P to nutrient uptake by cereals and rape on loam and clay-loam soils at Loon River, Scott and Rosetown. In May 1972 the present study was started on a coarse textured soil on the C.D.A. irrigation plots on the University farm in Saskatoon.

Specifically the objectives of this latter project were to determine: (1) the contribution of subsoil P to the nutrition of rapeseed plants, (2) the effectiveness of deep placement of P in coarse textured soils on the P uptake and yield of rapeseed, (3) the effect of available soil moisture on the uptake of subsoil depths before and after incubation with fertilizer P.

2. Experimental

All experimental work was started in May 1972 and has continued through to the time of this report.

2.1 Field studies

Span rapeseed was grown under different phosphorus placement and available moisture conditions on the C.D.A. irrigation test plot area of the University farm. The soil in this area has been classified as an Asquith Association, and consists chiefly of coarse textured chernozemic dark brown soils developed on lacustrine deposits. The surface Ap horizon which varies from 10-15 cm consists of dark greyish brown surface soil of fine sandy loam texture. The Bm horizon is approximately 15 cm deep and consists of olive brown loamy sand. The C horizon is a light olive brown fine sand. The physical and chemical characteristics of the soil at the experimental site are reported in Tables 1 and 2.

An experiment was carried out on this soil that involved growing Span rapeseed on this light textured soil under two moisture regimes

(normal precipitation, and adding irrigation water when the available soil moisture dropped to 60%). The complete plot area was therefore divided into two, one "dry" area and one "wet" area. Within both dry and wet areas there were four blocks measuring 30' by 30'. The north half of each block (i.e. an area 15' by 30') received phosphate fertilizer at a rate of 40 lbs of 11-48-0 at seeding, and in the south half the rapeseed was seeded without added fertilizer.

Moisture measurements were taken throughout the growing season using both surface and probe neutron moisture meters, and access moisture tubes were placed in each block. Soil temperatures were also recorded at 15 and 30 cm on both wet and dry areas. All areas received nitrogen fertilizer at the rate of 30 lbs of N/acre and a pre-emergence herbicide (Treflan) was also sprayed on the soil. Span rapeseed was sown on May 30, 1972. Furadan insecticide was mixed with the rapeseed and incorporated into the soil. Details of the experimental layout of the field plot can be seen in Figure 1.

The uptake of phosphate from depth was measured in two ways. On the area of the plot where rapeseed was seeded with phosphate fertilizer, P^{32} with carrier was injected at 30 cm and at 45 cm as illustrated in figure 2. The area treated in this way was 15 cm x 30 cm. In this 0.05 square meter area there were 15 holes for P^{32} injection. Plastic tubing was inserted into these holes to desired depths and the P^{32} solution was injected through the plastic tubing to 30 cm and 45 cm depth. Twenty-five mls (equivalent to 37.5 μCi)P^{32} and containing 0.595 g of mono-ammonium phosphate was injected into each 15 holes.

A similar placement of equivalent amounts of P^{31} solution at the same depth was carried out on an adjoining area of the plot (see Figure 2). On the portion of the plot where rapeseed had not been seeded with fertilizer, carrier free P^{32} solution was injected in a similar manner at 30 and 45 cm depths, respectively. A total of 140 μCi carrier free P^{32} was placed in each labelled 0.05 square meter area.

Plant samples were taken at seven time intervals during the growing season. Samples were taken from all the treatments on the same

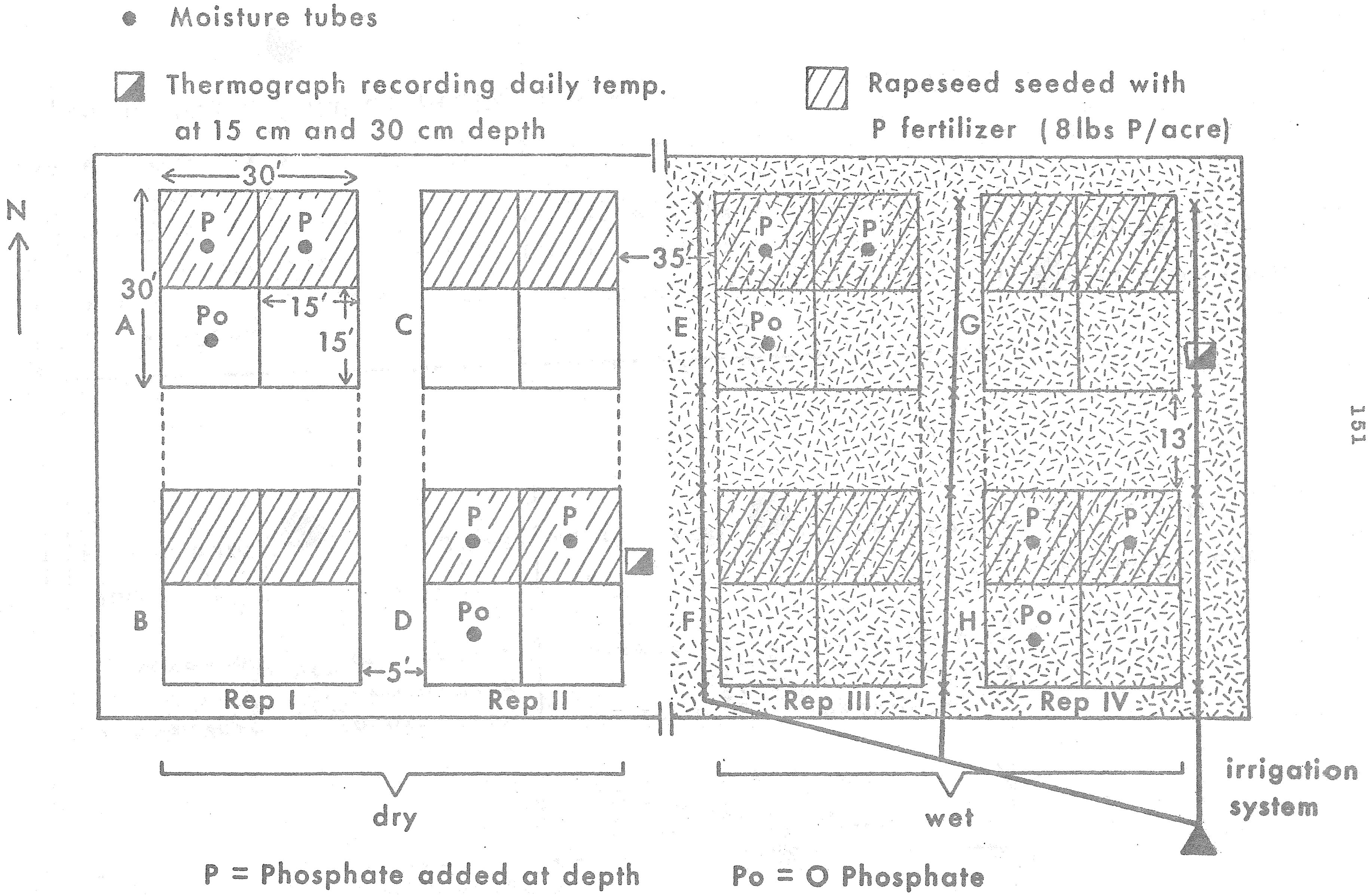

FIGURE 1. DESIGN OF FIELD EXPERIMENT

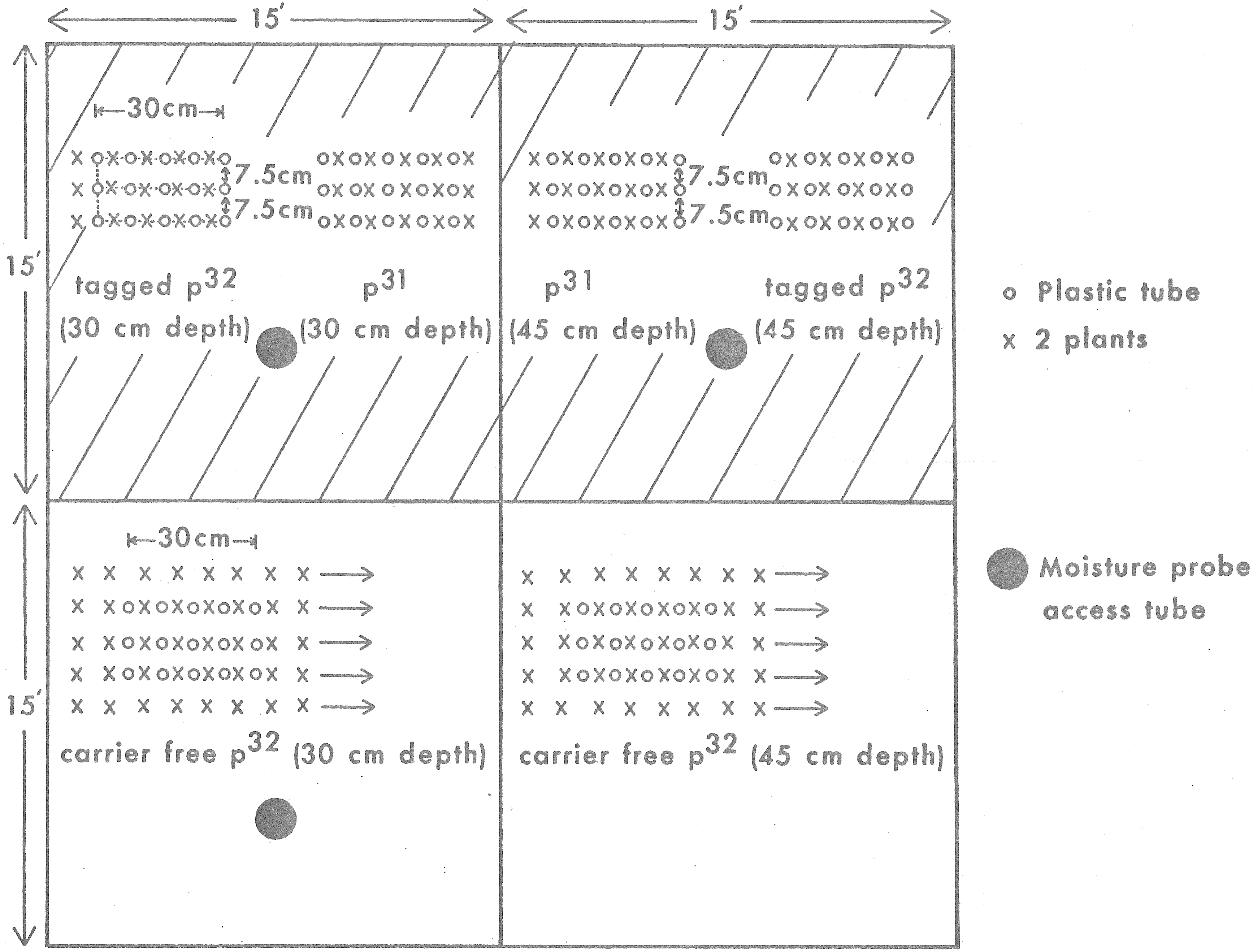

FIGURE 2. DETAIL OF BLOCK A IN THE FIELD EXPERIMENT

date. The plot was seeded on May 30, 1972, and the first sample was taken 25 days later, and then at irregular intervals until harvest. Plant samples were dried at 60°C for 36 hours and then were ground and analyzed for P content and P^{32} (where applicable). At the final harvest date the samples were separated into rapeseed and straw.

2.2 Root distribution studies

Root distribution studies were carried out on the field plot in late July. Both injection and leaf absorption of P^{32} was attempted in order to obtain a P^{32} labelled plant which then could be detected in soil cores taken from the surrounding area. Difficulty was experienced in both labelling methods. In this phosphorus absorption method, the leaves of the plants were bent and dipped into a carrier free P^{32} solution kept in a small plastic vial. However insufficient amounts of P^{32} were removed and distributed to the plant by this method. A second method tried was the stem injection technique which D. A. Rennie and E. H. Halstead had developed for wheat plants. Again this was not found to be successful. A modified injection technique was attempted. In this a small opening about 1.5 cm long and 0.5 cm deep was cut off from the stem of the plant. This small opening was filled up with a small piece of cotton wool, and 0.4 ml equivalent to 382 μCi of P^{32} was injected into the absorbing cotton wool. This method proved more successful in getting higher counts down to the roots. The main problem encountered in this root distribution method was that the P^{32} seemed to accumulate in the tap root in the top 0-15 cm in the soil, and the radioactive counts detected from the 0-15 cm soil root cores were much higher than the soil root cores taken from lower depths.(Fig.3)

2.3 Laboratory experiment

Incubation studies in which soil from the 0-15, 15-30 and 30-60 cm depths in the field were incubated with added mono-ammonium phosphate in a wetting and drying experiment which was designed to simulate field conditions. The availability of the added phosphate was measured in

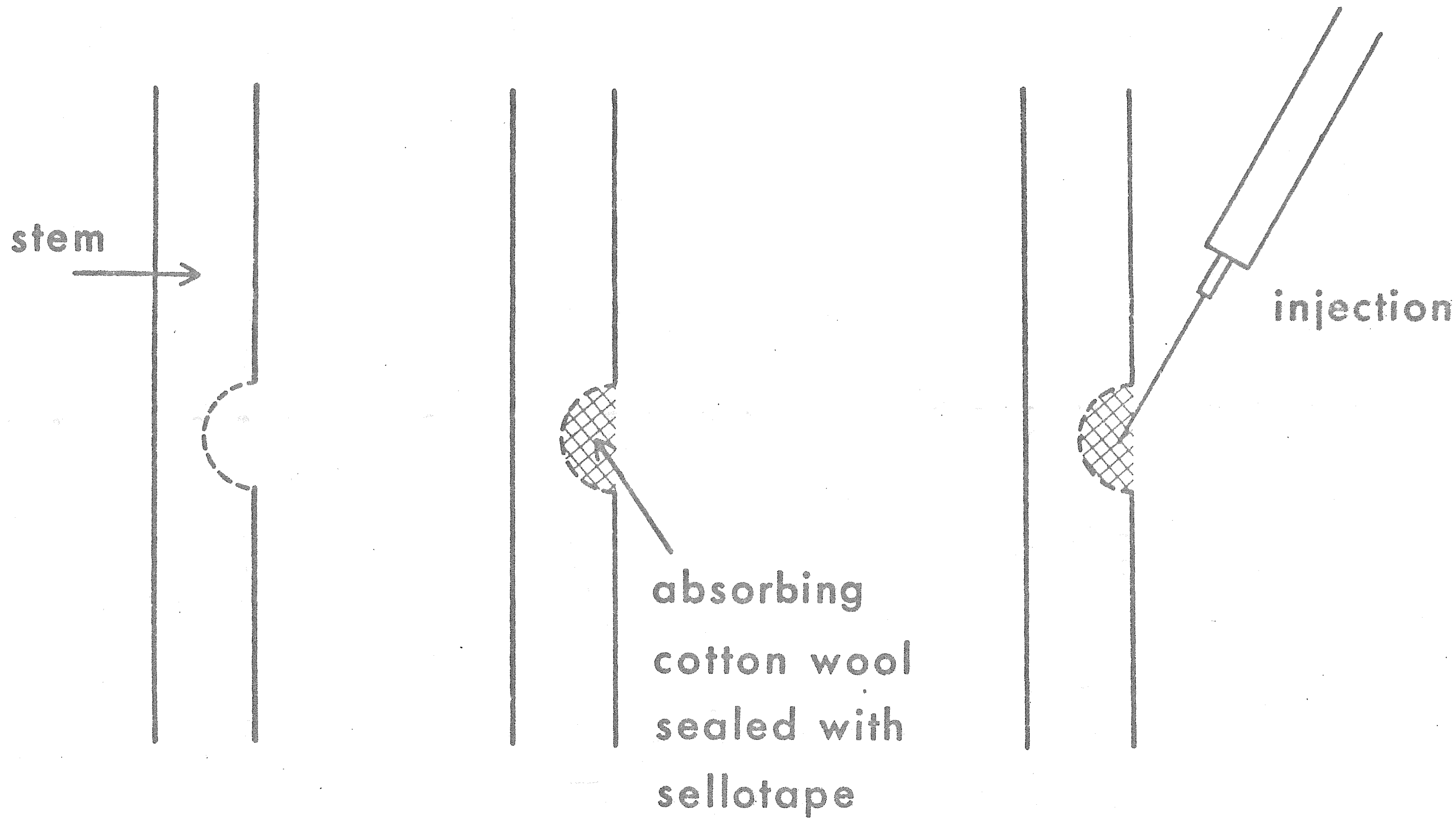

FIGURE 3. PLANT INJECTION FOR ROOT-DISTRIBUTION STUDIES

two ways. In the first, the forms of soil inorganic phosphate were determined before and after laboratory incubation; and in the second the phosphate potential and labile P status of the soil was measured before and after incubation treatment.

3. Results

3.1 Results from the field experiment

3.11 Yield data

The yield of rapeseed (both dry matter and grain) was increased by the addition of water. The total amount of irrigation water supplied during the year was approximately 12.5 cm (5 inches) and this was supplied at 4 cm H_2O in mid-June, mid-July and mid-August. Water was applied when the available water in the light textured soil dropped below 60% of field capacity. The addition of pop-up fertilizer with the rapeseed also significantly increased (at the 5% level) the yield of rapeseed. This yield increase was not expected as the level of available phosphate in the 0-15 cm soil layer was approximately 30 lbs of $NaHCO_3$-extractable P/acre. The current criteria used in the Saskatchewan Soil Testing Laboratory would rate soils with an extractable $NaHCO_3$ P level of greater than 30 lbs P/acre as containing sufficient phosphate and would not recommend fertilizer use. The increase of yield by the addition of phosphate was just significant at the 5% level, and fertilizer P may not have been justified from an economic standpoint. The phosphorus content of the harvested plant material also reflected (Table 4) the differences in phosphorus uptake.

3.12 Phosphorus uptake from 30 and 45 cm depths

3.121 Uptake of P^{32} added as carrier free material on the unfertilized plot under normal precipitation and under irrigated conditions

Analysis of rapeseed samples, taken at 25, 32, 37, 42, 47 and 62 days from seeding from the unfertilized plots to which carrier free P^{32} had been added at 30 cm and 45 cm, are presented in Table 5. At each sampling date the uptake of P^{32} from individual weighed samples was multiplied by the total weight of plant material estimated on the labelled area to determine the percentage of added carrier free P^{32} taken up by rapeseed. The results shown in Table 5 also show the time at which the phosphate at a specific layer is contacted by the plant roots. For instance, the rapeseed plant roots started to utilize phosphate at the 30 cm layer between 25 and 32 days after seeding; and 62 days after seeding, the amount of carrier free P^{32} utilized from the 30 cm layer varied from 30 to 40% depending on the water status in the soil. The roots in the dry plot intially took up the added P^{32} slowly, but eventually used more of the carrier free P^{32} than did the roots in the wet plot.

When carrier free P^{32} was placed at 45 cm the uptake was undetectable at 25 days, less than 4% on both water regimes at 32 days and significant at 37 days. Once again the roots in the dry plot were much more efficient in the utilization of the placed P^{32} than were the plots receiving irrigation water. This is a reflection of the general water use in the various soil horizons.

In the calculation of the data presented in Table 5, the uptake figures from a few plants within the experimental area had to be extrapolated to cover all the plants in the labelled area. As most of the plants were taken in the middle of the labelled area, there is a danger of over estimating the amount of phosphorus uptake from the complete area. Samples taken at the edge of the labelled area suggested that the percentage phosphate uptake could be over estimated. The data in Table 5 presents both maximum and minimum values, and an average of the whole plot area would probably lie between the two. Unfortunately, the size of the plots did not permit a more accurate assessment of the uptake values.

The data presented here agree very closely with the moisture use figures obtained over the growth period from the 15-30, 30-45 and 45-60 cm depths (Fig. 4), and also with the fact (Table 2) that there is a considerable amount of phosphate in an available form at depths in the plot area.

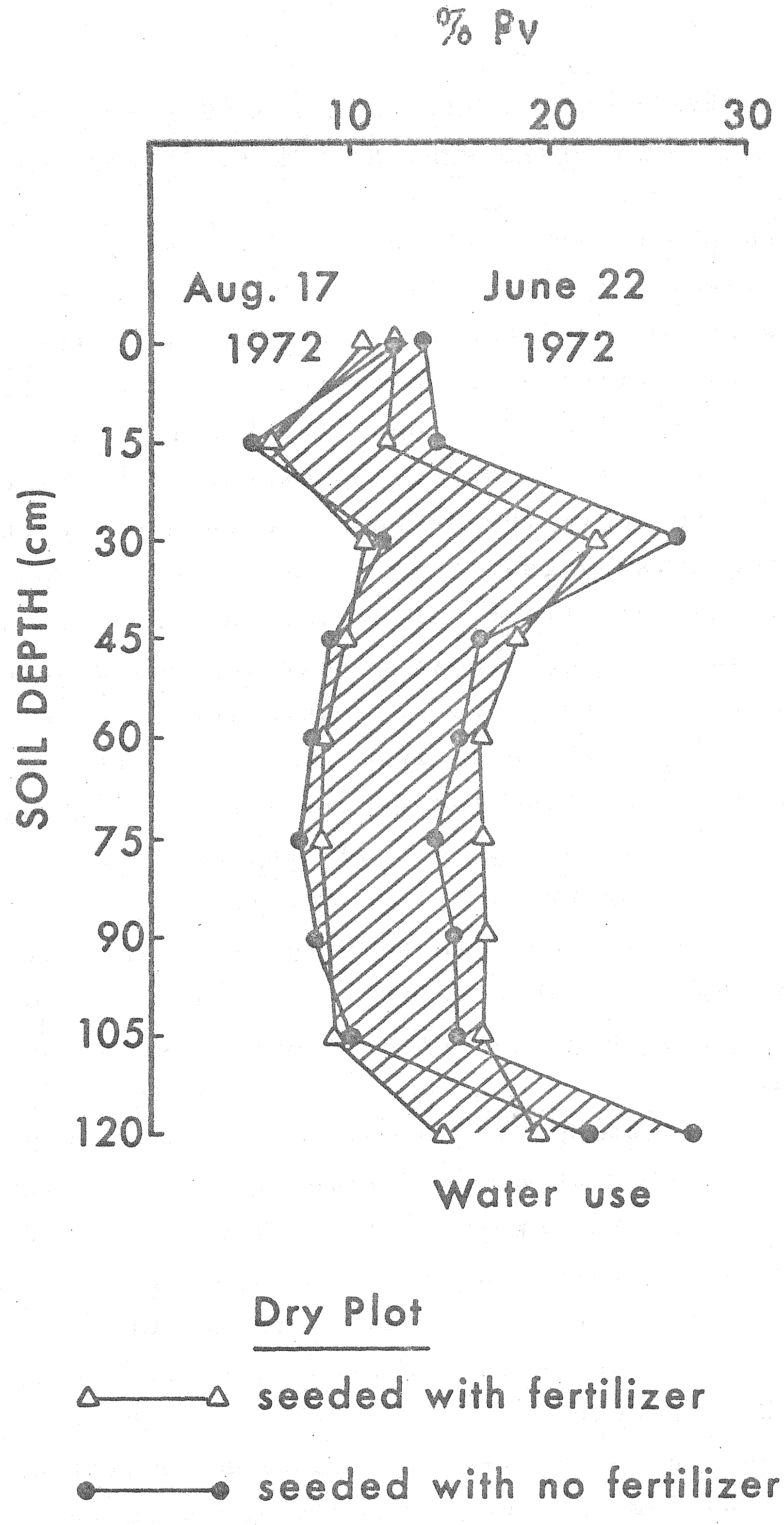

FIGURE 4. SOIL MOISTURE AT TWO SAMPLING DATES

3.122 Uptake of labelled P^{32} fertilizer placed at 30 cm or 45 cm depths in the soil where pop-up fertilizer was placed with the seed

When labelled phosphate fertilizer was placed at 30 and 45 cm depths in the soil which had received pop-up fertilizer with the seed, the same trends were shown as had been obtained with the carrier free phosphate. The data (Table 6) presents the results of this experiment in two ways. First of all as A-values (lbs P/acre) which give an indication of the value of the applied phosphate fertilizer. For instance, at the 30 cm depth the extremely high A-value obtained at the 25 day sampling date suggest that the labelled phosphate fertilizer was not being utilized at all at this time. As the season progresses, the A-values decrease markedly showing that the roots were using the radioactive fertilizer at the lower depths. The A-value is determined from the formula % of phosphate derived from the soil, over the % phosphate derived from the labelled fertilizer, multiplied by the rate of application which in this case was 445 lbs P/acre. The A-values therefore represent a comparison of the ability of the soil to supply phosphate in comparison to that placed at depth. The data in Table 6 also shows that when the labelled fertilizer was placed at 45 cm, it took approximately 42 days for significant amounts when used by the plant material.

Another means of looking at the data is to look at the percentage of phosphate in the plants which is derived from the labelled fertilizer and this is presented in the second half of Table 6. When the phosphate was placed at the 30 cm depth, the plant made use of it after 32 days; and when the phosphate was placed at 45 cm the uptake values showed that over 40% of the phosphate in the plant was derived from the fertilizer after 42 days growth.

This experiment again confirms that phosphate will be utilized in the soil at depths by the rapeseed plants under both irrigated and relatively dry conditions. The efficiency of application from depth is of course greater in the drier soil. Also comparison of the soil moisture data at two sampling dates, the first on June 22 after approximately 23 days growth, and the other on August 17 after approximately 78 days growth, show that considerable amounts of water have been utilized from both the 30 and 45 cm depths under the dry treatment (Fig. 4).

3.2 Laboratory experiment

Two laboratory experiments were carried out to obtain a measure of available phosphate in the soil before and after incubation with added fertilizer. The incubation technique involved a wetting and drying cycle in which 5.33 g of mono-ammonium phosphate was mixed with 2 kg of soil and the whole brought to field capacity. The pot soil was allowed to dry out in a growth chamber and then wetted to field capacity again. This cycle was repeated ten times. The form of soil inorganic phosphate was then determined using a fractionation procedure which had been modified from that used by Peterson and Cory (described in the Soil Science Society of American Proceedings 30:563-565). The results from the fractionation of the incubated soils in the A, B and C horizon are presented in Tables 7, 8 and 9, respectively. These tables show that the wetting and drying cycle did not change the readily available phosphate in the untreated soil. In all soils that had received additional phosphate and had been through the wetting and drying cycle, the majority of the phosphate still remained in the readily soluble P form, i.e. that extracted by ammonium chloride. The aluminum bound phosphate increased with added phosphate and incubation and supplementary data from other studies would show that this aluminum phosphate could still be used by plants in a highly calcareous soil. This data suggests that the transformation of added phosphate material to more insoluble forms is a slower process than has been anticipated. The possibility therefore exists that deep placed phosphate applied as a solution at depths from 15-45 cm in dry light textured soil in the fall would be utilized by deep rooting plants sown in the following season.

4. Summary and Conclusions

This initial work has shown that: (1) in light textured soils with deep rooting crops such as rape and alfalfa, appreciable amounts of phosphate will be taken up from depths below the plough layer (0-15 cm). (2) That if this is the case, the soil test correlation needs adjustment for lighter textured soils. (3) That on the soils there is a possibility of placing phosphate at depths below 15 cm and that the efficiency of utilization of this phosphate will compare very favourably with that placed in the 0-15 cm layer. (4) Laboratory work has indicated that phosphate applied as a solution (mono-ammonium phosphate in solution form) should remain in a plant available form for some time. This brings up the possibility of fall applications of solution phosphate at 15-30 cm depths in the soil with good utilization of applied phosphate by the crop grown in the next year. This particularly applies to lighter textured soils where the difficulty of placing the solution phosphate may not be so great.

These conclusions are mainly based on the work presented in this report, but are supplemented by studies carried out by co-workers at the University of Saskatchewan. Much more work is needed in this area, especially in the area of the soil test correlation with various deep rooting crops. However, the great advantage of having an intensive study on one site cannot be minimized.

6. Proposal for 1973 Summer

It is proposed that some of the work started in 1972 be repeated. The initial work on deep placement deliberately used high levels of phosphate application so that trends from the study could be clearly seen. In many cases, the rate of application was deliberately pushed much higher than an economic level. The 1973 program would again require the placement of phosphate at various rates at depths of 30 cm, 45 cm and 60 cm in the soil. Attention would have to be paid to the design of a field implement that would allow the fall application of solution P at these depths in light textured soils.

Table 1

Chemical properties of the plot soil

Depth (cm)	pH	Salinity mmhos/cm	Mechanical Analyses		
			% Sand	% Silt	% Clay
0-15	7.7	0.7	68.7	18.8	12.5
15-30	7.8	0.6	68.3	19.5	12.2
30-60	7.9	0.5	76.3	12.8	10.9

Table 2

Chemical properties of the plot soil

Depth (cm)	Total C (%)	Inorg. C (%)	Available Nutrients			
			NO_3-N	$NaHCO_3$-P	$NaHCO_3$-K	$CaCl_2$-S
			(lbs/acre)			
0-15	3.8	0.5	23	34	370	11
15-30	1.1	1.0	24	23	280	8
30-60	1.6	1.3	30	22	380	12

Table 3

Effect of added water and phosphate on the yield of rapeseed (each value is the average of 8 reps).

	Normal Precipitation		Irrigated Plot	
	No P	With P	No P	With P
Dry Matter kg/ha	4135	4158	6563	6823
Grain kg/ha	1120	1286	1950	2101
and				
(bu/acre)	(21.4)	(24.8)	(34.8)	(37.5)

P = 4 kg P/ha with seed.

Significant different > 0.1% level between normal precipitation and irrigated treatments.

Significant different 5% level between No P and P treatments.

Table 4

Phosphorus content (% P) of harvested plant material.

	Normal Precipitation		Irrigated Plot	
	No P	With P	No P	With P
Straw	0.047	0.049	0.074	0.079
Grain	0.567	0.605	0.689	0.670

Table 5

The percentage of the added carrier free P^{32} taken from a specific soil depth with time and under different water treatments.

a) Maximum value estimated from plant samples in the middle of the labelled area

Depth of P^{32} placement	H_2O treatment	Days from Seeding					
		25	32	37	42	47	62
		(% P)					
30 cm	dry	0.2	5.3	25.8	33.5	24.4	38.2
30 cm	wet	0.4	10.7	12.0	30.8	15.5	30.3
45 cm	dry	-	2.4	13.1	28.5	53.0	50.7
45 cm	wet	-	3.8	6.4	26.9	21.6	30.8

b) Minimum value estimated for plant samples at the edge of the labelled area

Depth of P^{32} placement	H_2O treatment	Days from Seeding					
		25	32	37	42	47	62
		(% P)					
30 cm	dry	0.1	3.5	17.0	22.1	16.1	25.2
30 cm	wet	0.2	7.1	7.9	20.3	10.2	20.0
45 cm	dry	-	1.6	8.6	18.8	35.0	33.5
45 cm	wet	-	2.5	4.3	17.7	14.3	20.3

Table 6

Uptake of phosphorus from placed fertilizers.

a) A-values

Depth of P^{32} placement	H_2O treatment	Days from Seeding					
		25	32	37	42	47	62
30 cm	dry	3170	554	416	403	339	235
30 cm	wet	5073	777	398	304	358	318
45 cm	dry	--	1333	1741	761	370	366
45 cm	wet	--	2240	950	654	478	455

b) % P in the plants derived from labelled fertilizer placed at depth

Depth of P^{32} placement	H_2O treatment	Days from Seeding					
		25	32	37	42	47	62
30 cm	dry	16.9	45.7	52.1	55.2	57.3	65.8
30 cm	wet	10.2	40.0	54.5	60.4	58.7	58.8
45 cm	dry	--	27.6	36.1	43.7	55.7	65.6
45 cm	wet	--	18.5	33.2	42.1	46.2	54.8

Table 7. Forms of soil inorganic phosphate in A horizon samples (0-15 cm depth) before and after laboratory incubation with added phosphate.

Incubation Treatment	Readily Soluble P (NH_4Cl)	Al-bound P (NH_4F/ H_3BO_3)	Fe-bound P (NaOH/ NaCl)	Ca-bound P (H_2SO_4)	Occluded P	Reductant Soluble P ($Na_2S_2O_4$-citrate)
	(μg P/g soil)					
W_0P_0	15	29	14	190	5	28
W_1P_0	18	19	4	210	6	34
W_0P_1	615	39	7	200	5	48
W_1P_1	470	146	11	230	5	89

W_1 = 10 Wet and Dry Cycles at 28°C over 4 months in the laboratory.

P_1 = 5.33 g of $NH_4H_2PO_4$ (26% P) per 2 kg soil.

Table 8

Forms of soil inorganic phosphate in B horizon samples (15-30 cm depth) before and after laboratory incubation with added phosphate.

Incubation Treatment	Readily Soluble P (NH_4Cl)	Al-bound P (NH_4F/ H_3BO_3)	Fe-bound P (NaOH/ NaCl)	Ca-bound P (H_2SO_4)	Occluded P	Reductant Soluble P ($Na_2S_2O_4$-citrate)
	(μg P/g soil)					
W_0P_0	7	17	2	220	4	27
W_1P_0	7	16	3	230	4	28
W_0P_1	380	21	2	255	5	35
W_1P_1	335	142	3	318	2	88

W_1 = 10 Wet and Dry Cycles at 28°C over a 4 month period in the laboratory.

P_1 = 5.33 g of $NH_4H_2PO_4$ (26% P) per 2 kg soil.

Table 9. Forms of soil inorganic phosphate in C horizon samples (30-60 cm depth) before and after laboratory incubation with added phosphate.

Incubation Treatment	Readily Soluble P (NH_4Cl)	Al-bound P (NH_4F/H_3BO_3)	Fe-bound P ($NaOH/NaCl$)	Ca-bound P (H_2SO_4)	Occluded P	Reductant Soluble P ($Na_2S_2O_4$-citrate)
	(μg P/g soil)					
W_0P_0	7	6	3	258	4	16
W_1P_0	5	9	2	260	2	18
W_0P_1	470	16	3	250	2	35
W_1P_1	425	97	5	285	3	88

W_1 = 10 Wet and Dry Cycles at 28°C over 4 months in the laboratory.

P_1 = 5.33 g $NH_4H_2PO_4$ (26% P) per 2 kg soil.